AIRS, the Atmospheric Infrared Sounder on EOS Aqua: The first five years of global spectrally resolved radiances

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Hyperspectral Infrared data provide a unique insight into the inner workings of the Earth Climate System

What have we learned from the first five years of AIRS data?

Did we find what we expected?

Outline

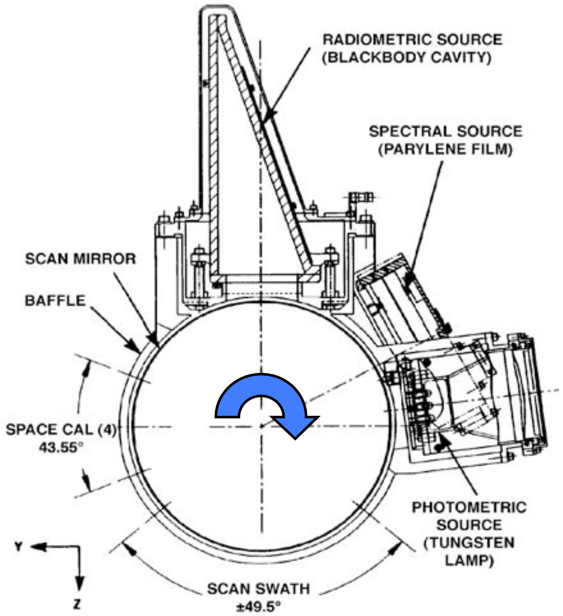
- Instrument
- Calibration and Validation
- Data Distribution
- Global and Regional Weather Forecasting
- Atmospheric Composition
- Climate Models
- Challenge
- Conclusions

The Atmospheric Infrared Sounder on NASA's EOS Aqua Spacecraft

AIRS Characteristics

- Launched: May 4, 2002
- Orbit: 705 km, 1:30pm, Sun Synch
- IFOV : 1.1° x 0.6°
  (13.5 km x 7.4 km)
- Scan Range: ±49.5°
- Full Aperture OBC Blackbody, $\varepsilon > 0.998$
- Full Aperture Space View
- Solid State Grating Spectrometer
  - **IR Spectral Range:**
    3.7-4.6 µm, 6.2-8.2 µm, 8.8-15.4 µm
  - **IR Spectral Resolution: ≈ 1200 ($\lambda/\Delta\lambda$)**
  - **2378 independent IR Channels**

- Mass: 177Kg, Power: 256 Watts,
  Life: 5 years requirement
  current best estimate is 12 years
  limited by spacecraft propellant.



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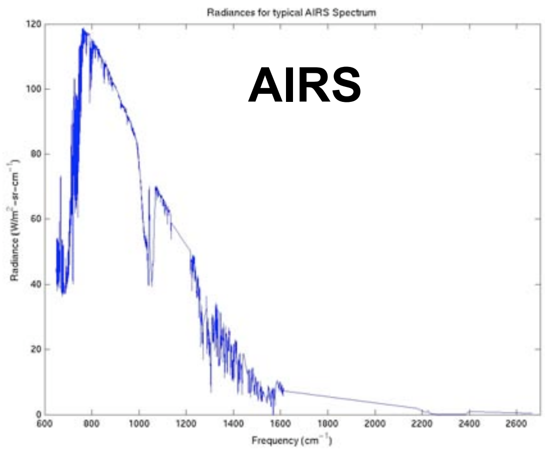
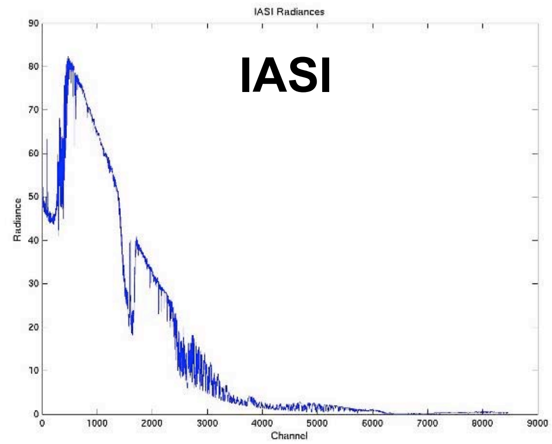
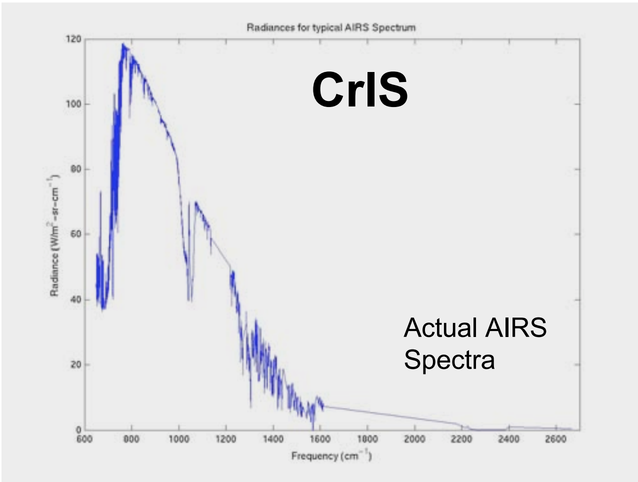
AIRS is the first of a series of operational hyperspectral infrared sounders



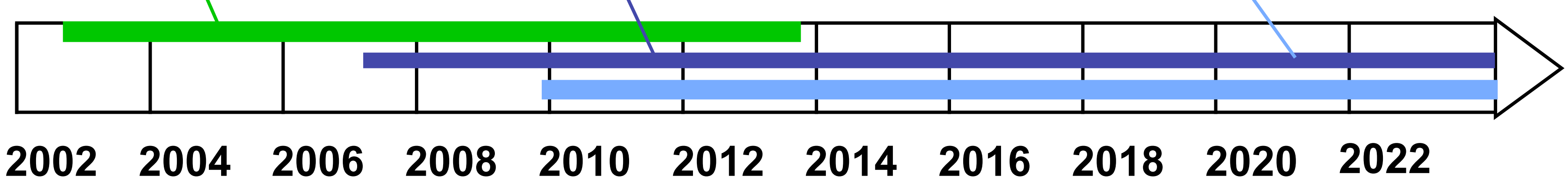




AIRS on Aqua
1:30 PM Orbit
14 km GSD
±49.5° Swath

IASI on MetOp
9:30 AM Orbit
12 km GSD
±49° Swath

CrIS on NPOESS
1:30 PM Orbit
14 km GSD
±48.3° Swath
NPP: 2009 C1: 2013
C3: 2020



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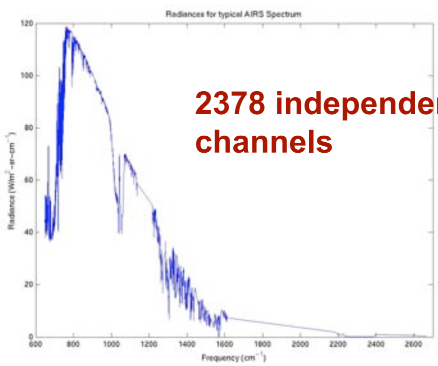
AIRS L1B Radiometric and Spectral Accuracy and Stability validated on orbit

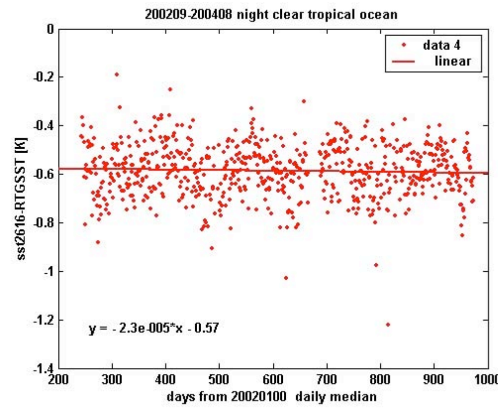
AIRS L1B Hyperspectral Climate Data Record (CDR) over 5 Billion Spectra



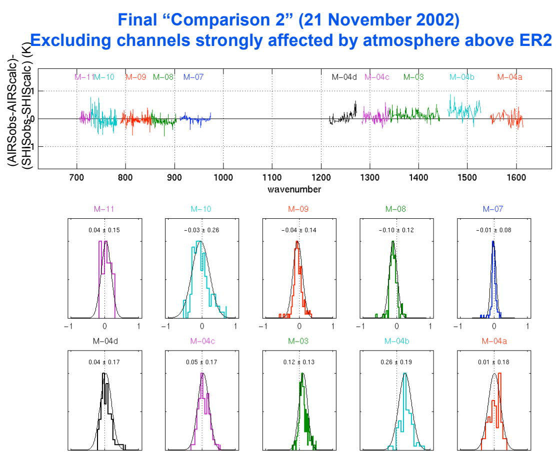
2378 independent channels

Reference: JGR, VOL. 111, April 2006

AIRS L1B Radiometric Performance: Stable to <8mK/Year – H. Aumann et al. 2006

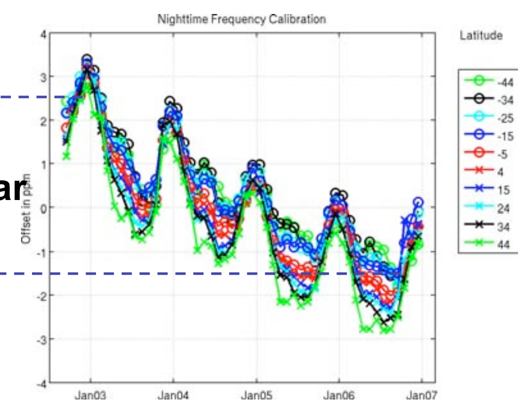


SHIS Validates Radiometric Accuracy to 0.2K – H. Revercomb et al. 2006



AIRS L1B Frequencies Knowledge to < 1 PPM - L. Strow et al. 2006

< 1 ppmf/year in Level 1B



L1B Scene Independent

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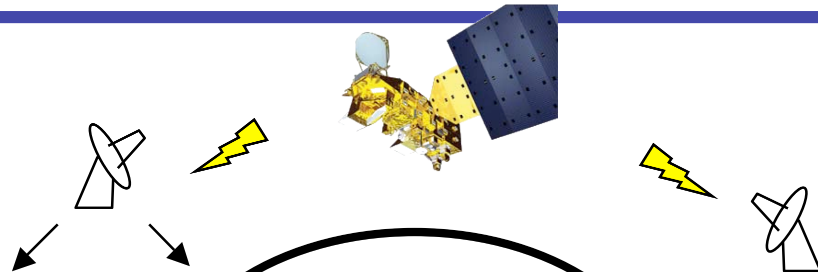
AIRS/AMSU data are widely distributed



NOAA NESDIS (Weather/ Hazards)

GSFC DAAC (Climate)

DIRECT BROADCAST (Hazards/ Weather)

NWP Centers
NCEP, GLA, CMC, JMA, FNMOC,BOM, UK Met, ECMWF, Meteo Fr., DWD

- **Science Community**
- **Public**
- **JPL**

- **Universities**
- **Local Weather Stations**
- **Brazil (INPE)**
- **China**
- **Korea**
- **DoD**
-

http://daac.gsfc.nasa.gov

Weather and Climate

- **Improved weather predictions is the primary objective of hyperspectral infrared sounders.**

global medium range predictions

regional medium range predictions

long range predictions = climate

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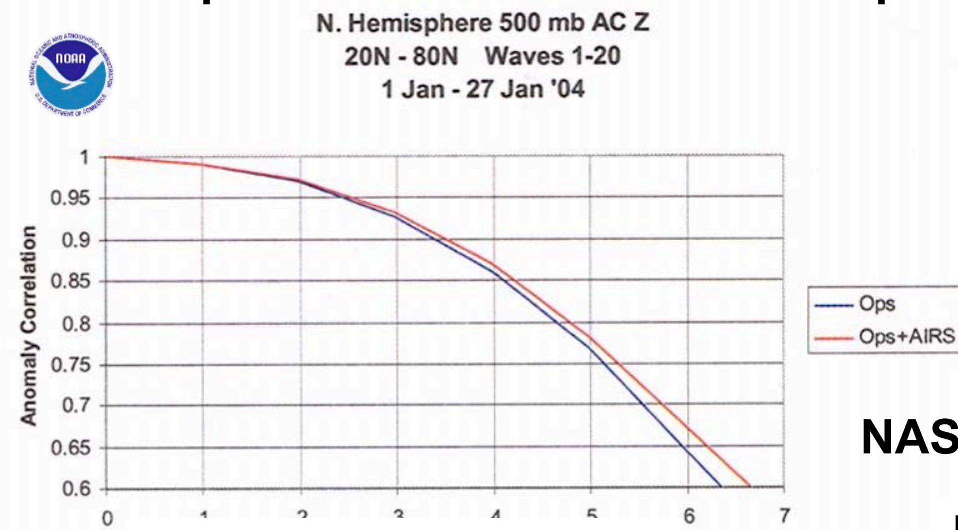
AIRS data have improved the operational weather forecasts

NCEP Operational Global Forecast Improvement

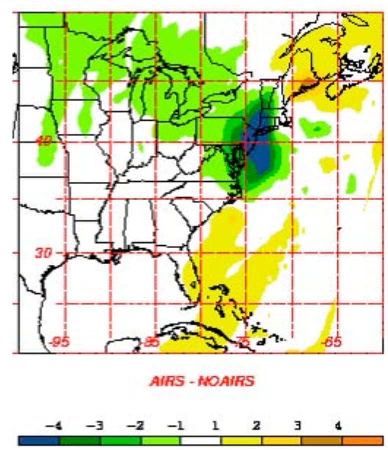


6 hrs for 6 day forecast

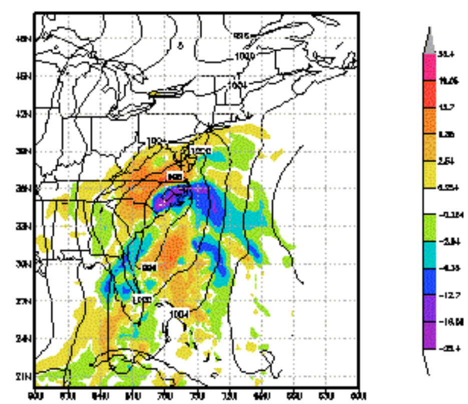
J. LeMarshall, JCSDA
BAMS (2006)

NASA Regional Forecast Improvement

Pressure



Rainfall



B. Zavodsky, NASA SPoRT

AIRS data are not fully utilized

The strength of hyper-spectral infrared observations is their sensitivity to water vapor AND clouds,

But

the cloudy data from AIRS have this-far been avoided in the assimilation.

difficulties have emerged with water vapor assimilation using 4DVar

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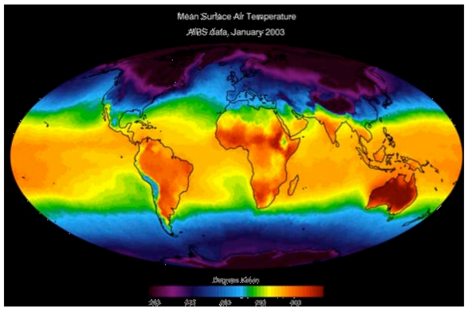
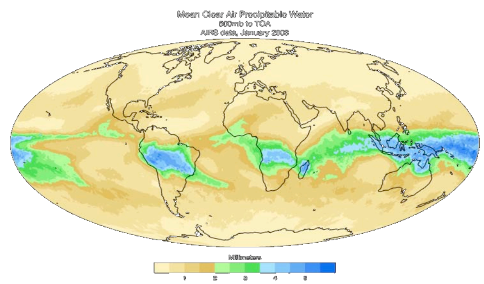
AIRS provides a wide range of products useful for weather and climate studies

[..] under development

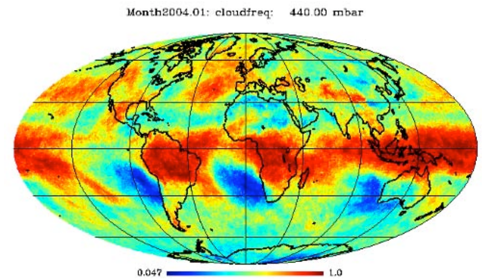
Atmospheric Temperature



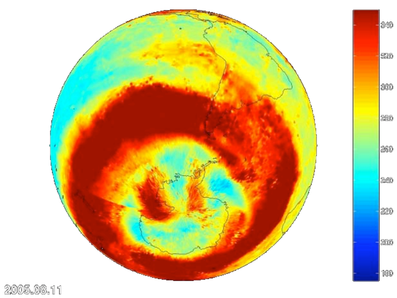
Atmospheric Water Vapor



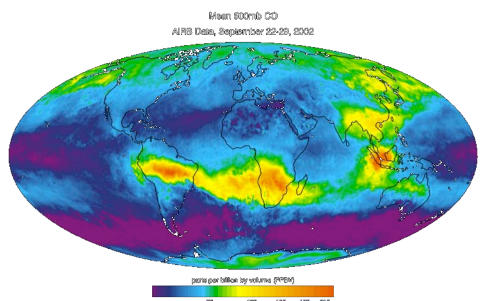
Cloud Properties



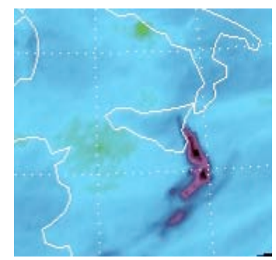
Ozone



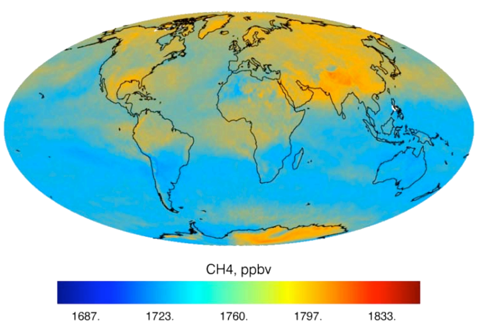
CO



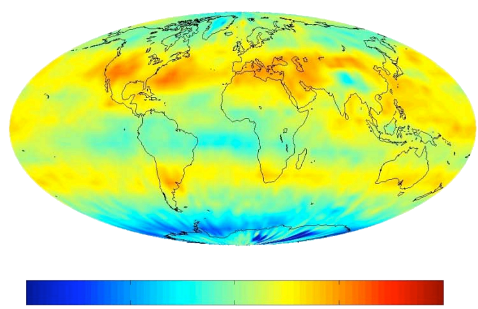
[SO2]



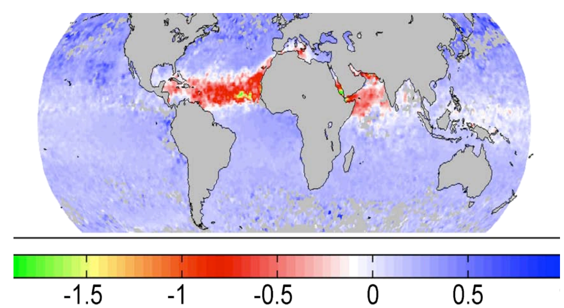
[Methane]



[CO2]



[Dust]



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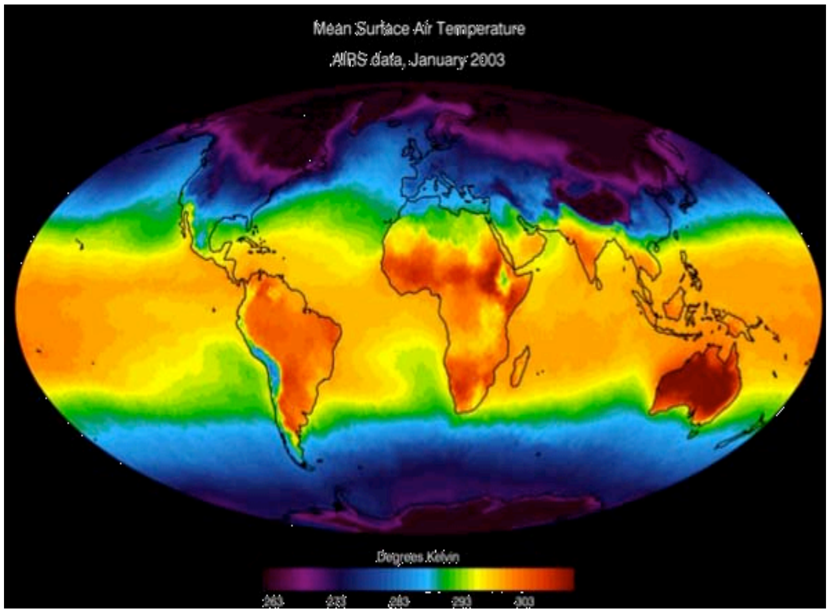
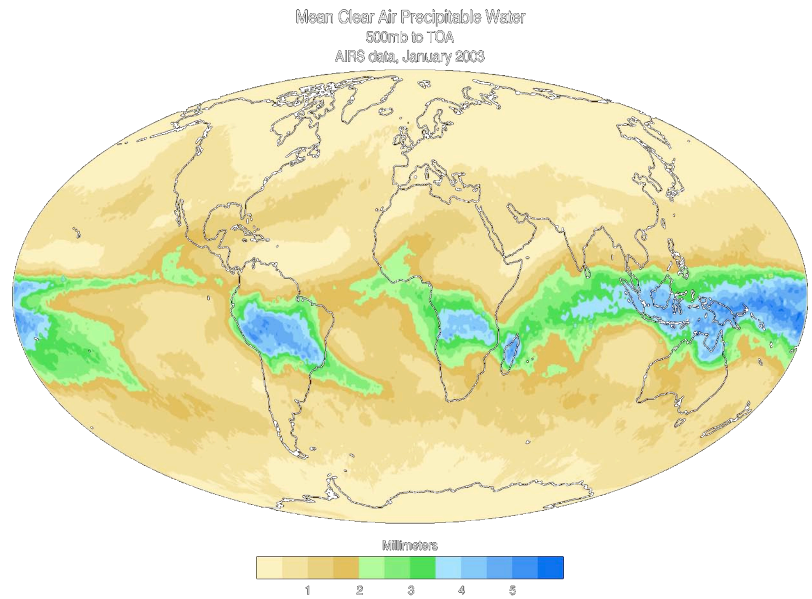
AIRS global temperature and moisture profiles match RAOB accuracy

Atmospheric Temperature



Atmospheric Water Vapor

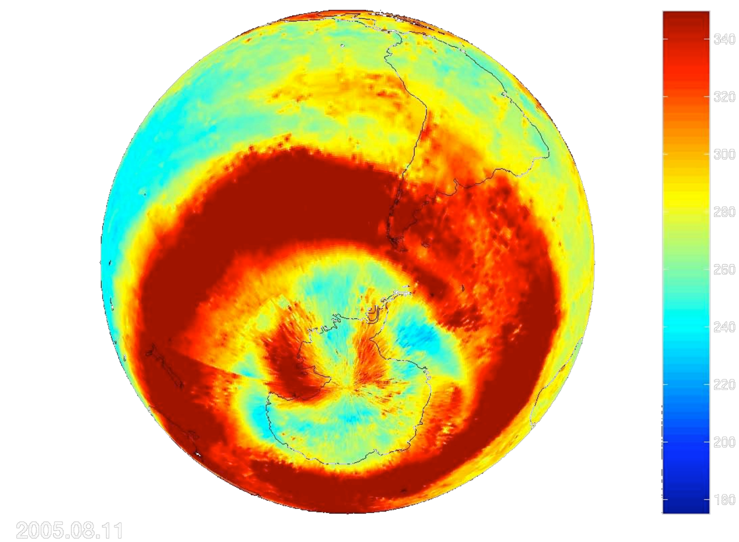


Divacarla et a. 2006

AIRS 3D Ozone Profile Allows Viewing Stratospheric Tropospheric Exchange

- Ozone
  - AIRS/AMSU data map the global distribution of O3 for all seasons of the year.
  - AIRS average total column O3 matches to within 5% of that observed by Total Ozone Mapping Spectrometer (TOMS) (Irion et al. 2006)
  - AIRS observes Stratospheric Tropospheric Exchange (Pan et al. 2006)

Total Column Ozone (DU)

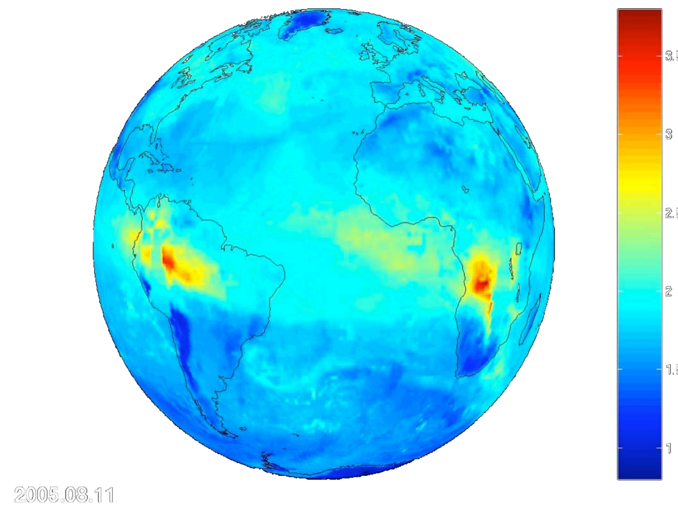


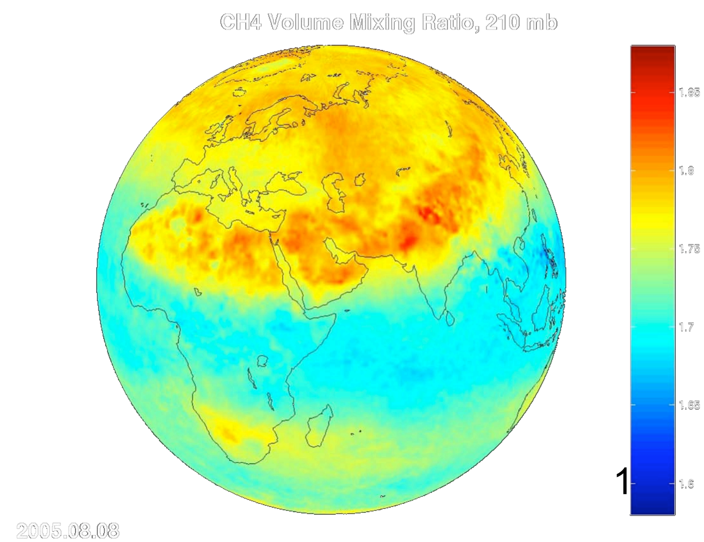
AIRS Ozone Profile

AIRS Carbon Monoxide and Methane

- **CO**
  - **AIRS/AMSU data have provided the detailed, daily global observation of transport of mid-tropospheric CO from biomass burning emissions (McMillan et al. 2005, McMillan 2006).**
  - **AIRS CO retrievals have been found to validate the plume rise mechanism in simulations of the transport of CO in the mid-troposphere (Freitas et al. 2006).**
- **CH4**
  - **AIRS/AMSU have started to create monthly mean CH4 maps to study the seasonal variation.   (Yu et al. 2005 and Gribanov et al. 2007).**

Carbon Monoxide (DU)





CO_2 Retrievals with hyperspectral sounders

Chedin, A., et al. (2003), The feasibility of monitoring CO2 from high-resolution infrared sounders, J. Geophys. Res. (USA), 108.

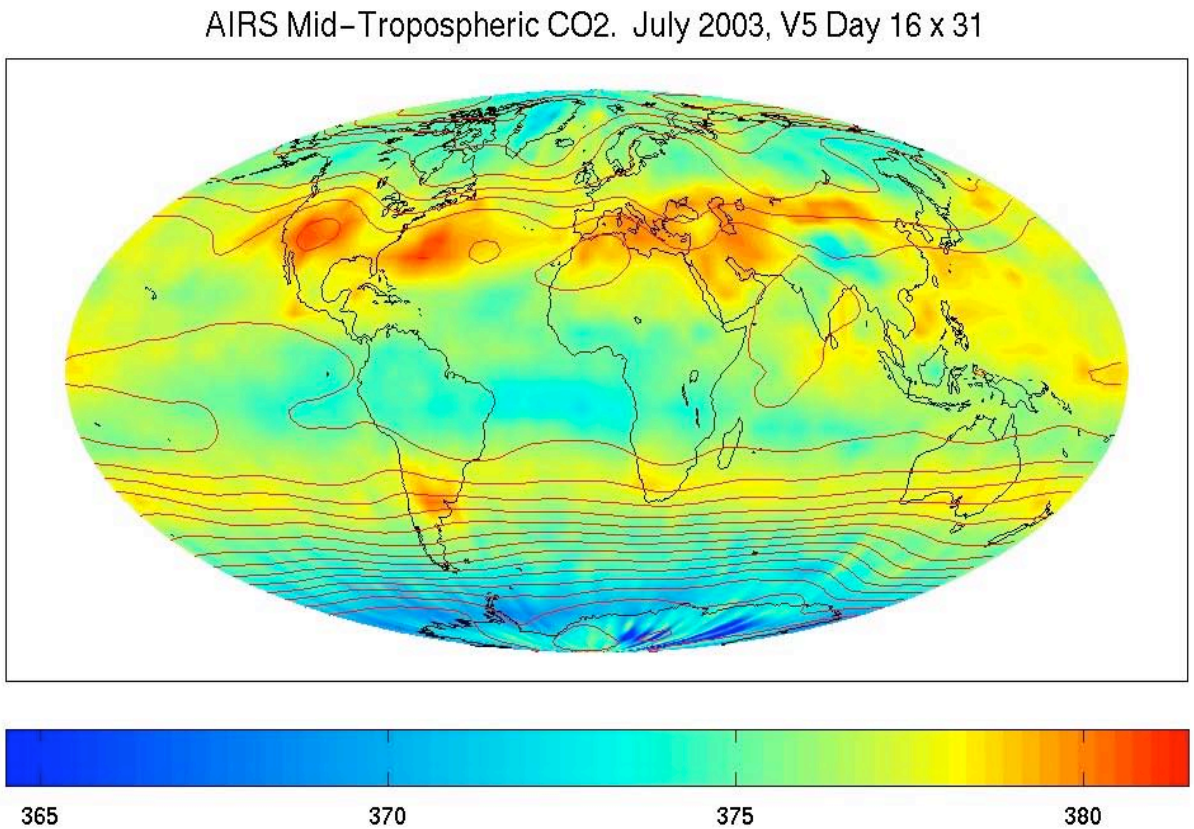
Engelen, R. J., et al. (2004), Estimating atmospheric CO2 from advanced infrared satellite radiances within an operational 4D-Var data assimilation system: Methodology and first results, Journal Of Geophysical Research-Atmospheres, 109.

Crevoisier, C., et al. (2004), Midtropospheric CO2 concentration retrieval from AIRS observations in the tropics, Geophysical Research Letters, 31, 17106.

Aumann, H. H., et al. (2005), AIRS hyper-spectral measurements for climate research: Carbon dioxide and nitrous oxide effects, Geophysical Research Letters, 32, 05806.

Chahine, M. et al. (2005) "On the determination of atmospheric minor gases by the method of vanishing partial derivatives with application to CO2". Geophys. Res. Lett., Vol. 32, No. 22, L22803 10.1029/2005GL024165.

Global CO_2 Retrievals made possible by AIRS Sensitivity and Stability



200 x 200 km spatial mean

red contours are the 500 hPa pressure altitude

Chahine et al. (2008) in preparation

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Climate Models

Five years of AIRS data identify discrepancies in climate models

1. **Discrepancies in large regional comparisons of AIRS retrieved water vapor to model water vapor**

2. **Discrepancies in zonal studies comparing AIRS radiances to radiances calculated from climate models**

3. **Discrepancies in zonal studies comparing the phase of products from AIRS/AMSU/CERES with climate models.**

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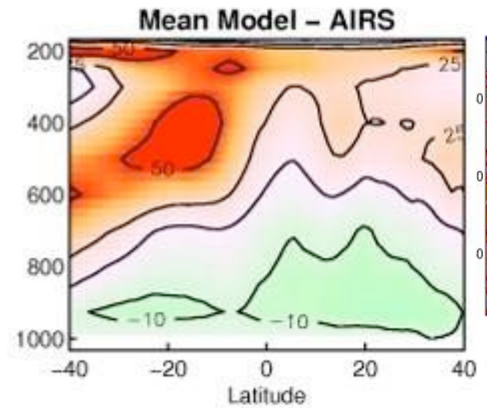
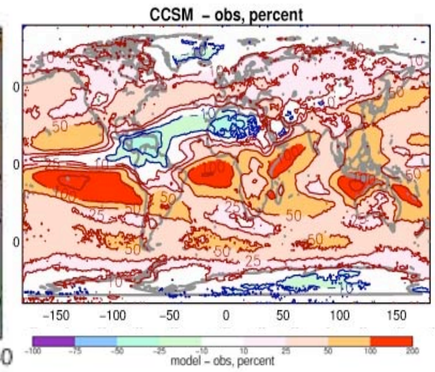
Climate Models are too wet in the middle and upper troposphere

Method 1: Amplitudes

- **L3 Comparison**
  - The models are drier than AIRS observations by 10%-25% in the tropics below 800 hPa.
  - The models are more moist by 25%-100% between 300 and 600 hPa, especially in the extra-tropics.

    ** David W. Pierce et al. 2006*





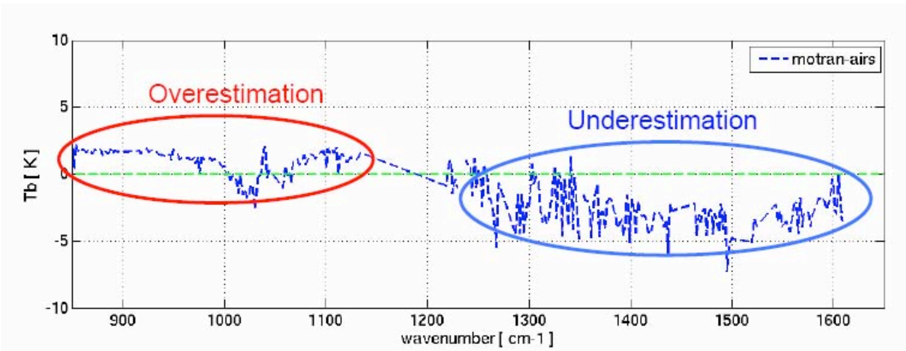
- **Radiances (L1b) Comparison**
  - AIRS OLR Agrees with Models

    but there are compensating Errors

    Models wet in the upper troposphere ((flux too low) compensated by too much surface flux

    ** Huang et al. 2007.*

Unit: W m^{-2}	OLR		Window band	
	Total sky	Clear sky	Total sky	Clear sky
CERES	241.73	275.87	66.94	83.28
AM2	240.63	263.43	73.99	87.56
AM2-CERES	-1.10	-12.44	7.05	4.28



Difficulties with scale are emerging

Clouds and water vapor are highly non-linear and are difficult to deal with on the 100 km scale in medium range forecasting or the 10 km scale in the regional forecast.

These difficulties are much more obvious when dealing with climate models on a global scale.

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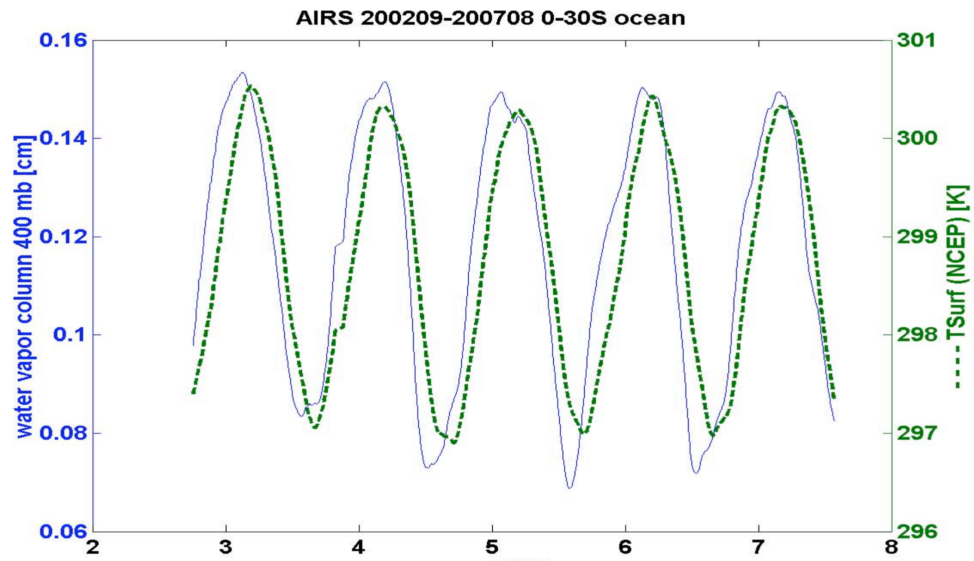
Climate model show seasonal phase errors

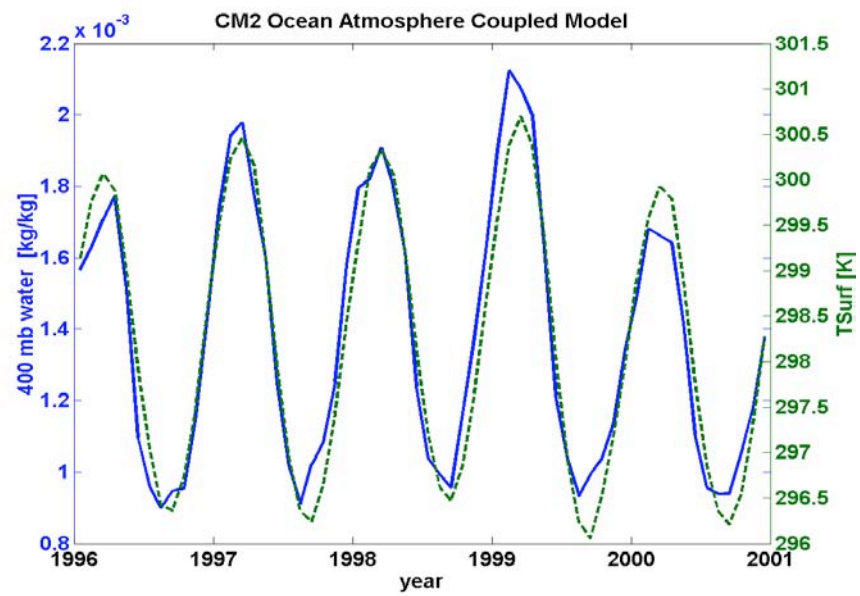
Method 2: Phase Analysis

compare monthly mean zonal variability from climate models with AIRS observations

Aumann et a. 2007 GRL



Significant differences in phase and amplitude between GFDL/CM2, NASA/GISS and NRL/CCMD climate models and observations form AIRS, AMSU and CERES.



Potential Improvements

The observational scale for water vapor in the boundary layer and clouds at all altitudes is of the order of 1 km

Clouds and water vapor averages on a the 10 km scale are difficult to interpret

Land the emissivity scale is 1 km (based on ASTR and MODIS << 1 km data)

The AIRS 12 km spatial resolution is a limiting factor

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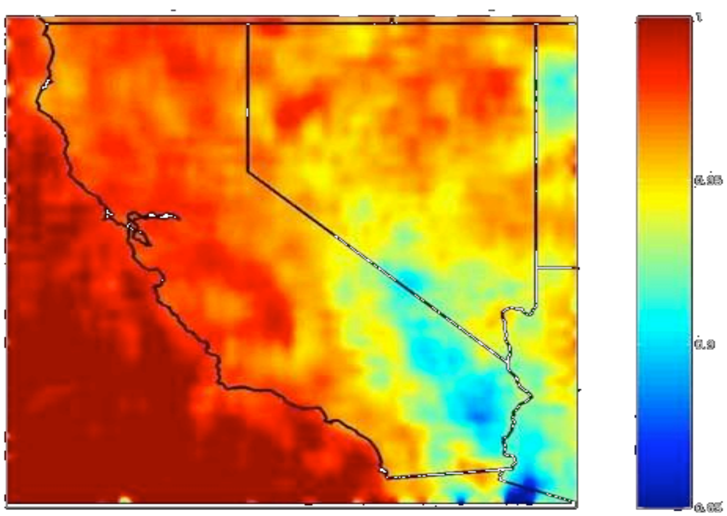
AIRS 12 km spatial resolution limits accuracy of products

<u>AIRS Emissivity</u>

50x50 km

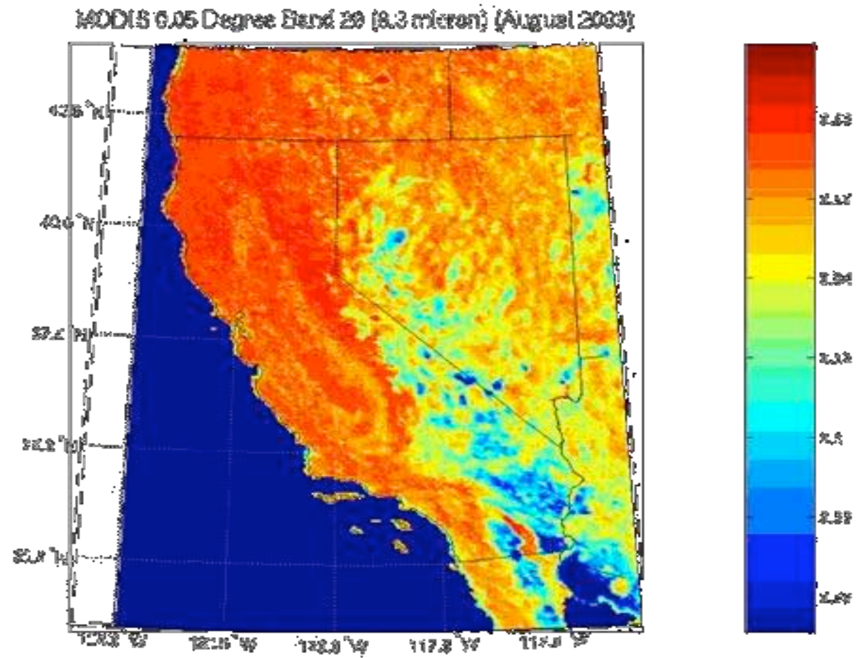
v = 1095 cm^{-1}



<u>MODIS Emissivity</u>

5x5 km

v = 1205 cm^{-1}



A hyperspectral sounder with AIRS-like NeDT and 1 km spatial resolution is feasible

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The Challenge

Hyperspectral Infrared data provide a unique insight into the inner workings of the Earth Climate System

The first five years of AIRS data have

met all expectations

provide the unique opportunity to discover the unexpected

Super Cell near Chaparrel NM

Photo 3 April 2004 8pm, AIRS 4 April 2004 1:30 AM

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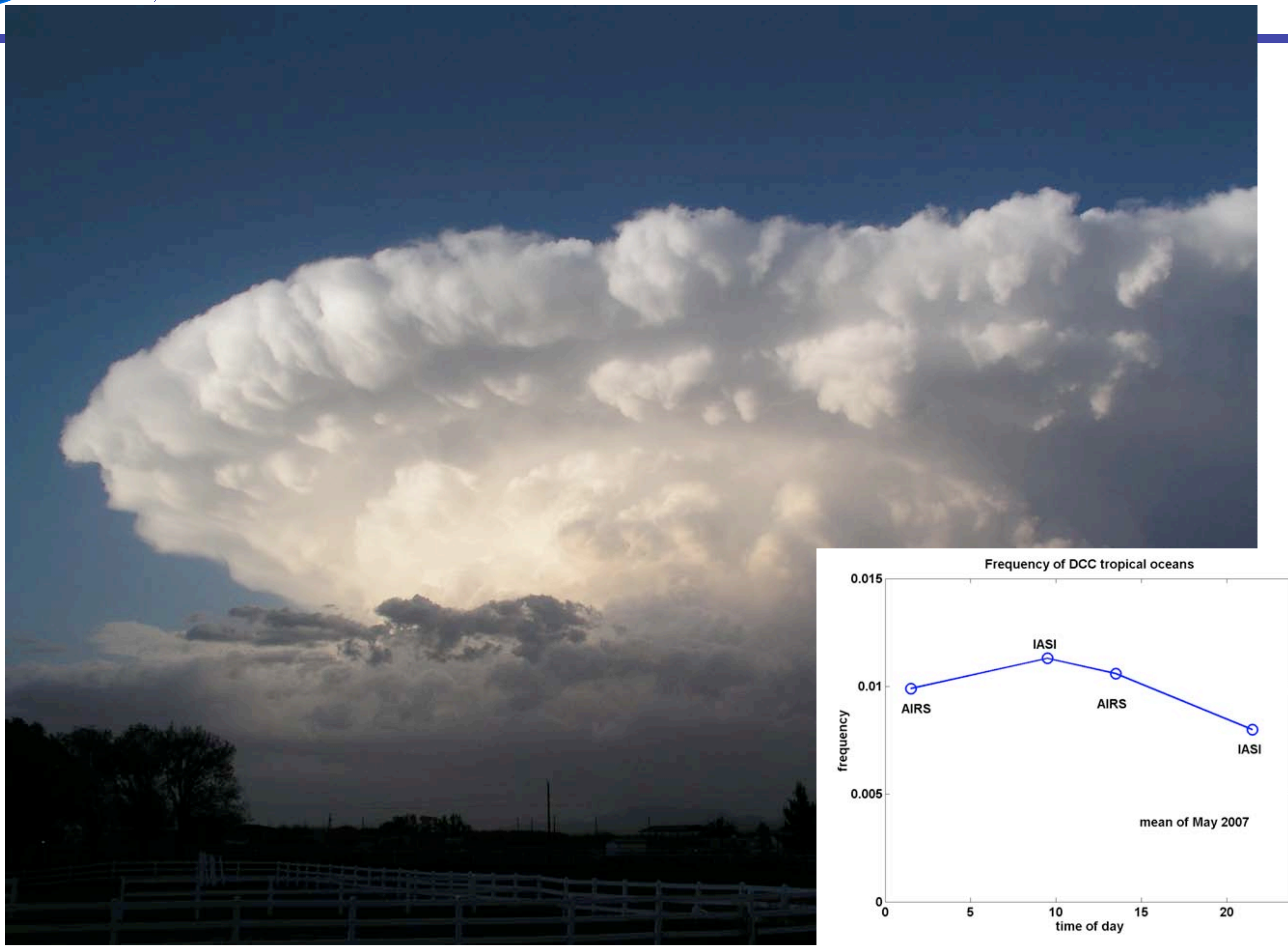
Super Cell near Chaparrel NM

Photo 3 April 2004 8pm, AIRS 4 April 2004 1:30 AM



Summary

AIRS is achieving what was expected

- **Global hyperspectral infrared with high accuracy and stability**
- **Forecast improvement are achieved by cloud-free radiance assimilation**
- **AIRS tracegases monthly maps are starting to support global transport studies in the mid troposphere (AGU San Francisco Dec 2007 Session)**
- **Applications to climate models is starting**
  (AGU San Francisco Dec 2007 Session)

Discovery of the unexpected is the challenge

Conclusions

- **Major forecast impact from hyperspectral sounders requires dealing with clouds at the 12 km level and less.**

- **The spatial scale of water vapor and clouds are limiting observational factors in process studies at the 1 km level**

  A hyperspectral sounder with AIRS-like NeDT and 1 km spatial resolution is feasible

For more information on AIRS see

– **http://airs.jpl.nasa.gov**